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THE EXCURSION TO THE PYRENEES IN CONNECTION WITH THE EIGHTH INTERNATIONAL GEOLOGICAL CONGRESS

THE origin of the ancient crystalline rocks of the earth's crust is a subject which has always possessed a peculiar interest for geologists and which, now that the progress of investigation seems to bring the solution of the various problems connected with these rocks almost within our reach, has a greater attraction than ever.

One of the most important lines of evidence bearing upon this question is that derived from the study of the contact zones about intrusive masses, but the effects produced by many of these intrusions have been differently interpreted by different observers.[1] In France especially, Michel-Lévy, Barrois and Lacroix have described intrusive granite masses, which have not only intensely altered the strata through which they pierce but which have produced a wholesale transformation of the sedimentary rocks in question into granite, the granite now occupying the space formerly occupied by the sediments. If this be the origin of granite, a knowledge of the fact would have an important bearing on the interpretation of many occurrences in the Archean, but the great majority of geologists have been unable to find evidence of it in their respective countries. The French Pyrenees have, however, been cited by Lacroix as a district in which these remarkable transformations could be seen with especial clearness, and in connection with the International Congress of Geologists held last summer in Paris, an excursion to the Pyrenees was accordingly arranged, under the leadership of Professor Lacroix, in order that the members of the congress might have an opportunity of seeing these transformations in the district made classic by Professor Lacroix's work. It is proposed in the present paper, first to give a short account of this excursion and then to discuss briefly some points in connection with the explanations offered by Lacroix of the phenomena observed.

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[1] ADAMS, F. D.: A review of some recent papers on the Influence of Granite Intrusions upon the Development of Crystalline Schists. JOUR. GEOL., Vol. V, 1897.

Leaving Paris on the morning of August 3d on our way south to the rendezvous of the excursion at Ax-les-thermes, the great Tertiary plain of northern France was first traversed. The country as far as the eye can reach is quite flat and excellently cultivated. The grain had just been cut and stacked, and the country in appearance afforded a marked contrast to those portions of the southeast of England underlain by rocks of the same age, in the entire absence of the picturesque hedges and of standing timber. The train then gradually ascended the table land of the Plateau Central, from which far to the east rose the volcanic peaks of the Auvergne, and the country assumed a more rolling character. Descending from this plateau on its southern side over strata of Jurassic age, past Brive and Souillac, the landscape underwent still another change, the country becoming in many places rough and broken, with great exposures of bare rock on either side, through which the train threaded its way in numerous tunnels and rock cuttings, and as the night closed in reached the old city of Montauban. Next morning, passing over the Tertiary basin of southern France, through Toulouse and up the wide low walled valley of the Ariège, Foix was reached, about which place the valley narrowed and the foothills of the Pyrenees rose high and abrupt on either side. Thence passing on by Tarascon the train reached Ax-les-thermes, a picturesquely situated little town, lying well within the Pyrenees, whose hot springs and baths annually attract a large number of visitors, chiefly from other parts of France.

Here the members of the congress who were to take part in the excursion, twenty-eight in number, coming from various parts of Europe and America, were received by Professor Lacroix. Five of the party only claimed English as their native language; Mr. Arnold Hague, Professor Wolff and Dr. Ries representing the United States, while Mr. Kynaston, of the Geological Survey of Scotland, represented the United Kingdom.

The following day, August 5th, the regular work of the excursion began, two visits being made, from Ax-les-thermes as headquarters, on consecutive days, to the contact of a large mass of granite, several miles to the northeast of Ax-les-thermes in the heart of the Pyrenees, with a series of shales and limestones believed to be of pre-Cambrian age. The exact age of the granite is not known but it is younger than the Carboniferous and older than the Lias.

The contacts seen on the first day, were chiefly in the vicinity of the beautiful little L'Etang de l'Estagnet, from which there rise on either side great walls of bare rock, and well graded talus slopes affording abundant exposures. (See Figure 1.)[1] The normal granite of the district is light in color, poor in iron magnesia constituents and contains large porphyritic feldspars. It often shows marked evidences of dynamic action. The shales near the contact are hardened, being converted into a hornstone, said by Lacroix to be in many places "feldspathisé," but the most interesting feature of the excursion was the contact of the granite with the limestone. This limestone, which is gray in color and highly crystalline, contains many little bands of silicates, representing impure laminæ in the original rock, which, especially on the weathered surface, emphasize its stratified character in a most striking manner and often display the most complicated contortions. The limestone in its whole character and appearance exactly reproduces many occurrences seen in the more altered limestones of the Hastings Series in the Archean of Canada.

Between the limestone and the granite, however, there is a zone of rock, often very narrow but in some places, according to Lacroix, as much as 800 meters wide, more basic than the granite and termed by Lacroix, "Diorite" or "Roche Dioritique." This completely surrounds certain isolated occurrences of limestone and is believed by Lacroix to have been produced by the granitic magma, before crystallization, dissolving a portion of the lime-stone, incorporating it, and thus being rendered more basic, crystallizing out as a diorite about the contact. This "Roche Dioritique," while as a general rule tolerably uniform in appearance, often presents rapid variations in size of grain from fine to coarse, and in other places passes into more basic forms such as norite and even into varieties holding olivine.

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[1] For the photographs which illustrate this paper, with the exception of that reproduced in Fig. 2, the author is indebted to Professor Heinrich Ries, of Cornell University.

The excursion of the second day took the party to another portion of the periphery of the same granite mass in the wild district about the L'Etang de Baxouillade (see Fig. 2) and the Cirque de Camp Ras. The route followed led first over the granite, which as the contact was approached was seen to hold a few dark inclusions, which certain of the petrographers present at once set down as basic secretions from the magma. These, as the little L'Etang de Baxouillade was passed become more numerous and often presented the appearance of having been softened and drawn out. Further on at the Cirque de Camp Ras the granite comes against a mass of shale interstratified with limestone. Both of these rocks are highly altered, the shales being converted into dark hornstones and the limestones into paler lime hornstones, consisting chiefly of a basic feldspar and pyroxene. Along the immediate contact of the granite, there appears to be evidence that the dark inclusions before mentioned are masses of hornstone which have been separated from the walls, caught up by the granite magma and more or less softened —or in the case of the lime hornstone dissolved, giving rise to irregular shaped masses of the "Roche Dioritique" before mentioned. One block of gneissic granite about two feet long was observed, at one end of which, embedded in the granite was a mass of the light-colored hornstone enclosing a mass of unaltered limestone, while at the other end of the same block, the granite contained small masses of "Roche Dioritique," which certainly presented the appearance of dissolved fragments of the same limestone. The only other explanation of the origin of these darker-colored masses in the granite is that they are basic secretions from the granite magma itself, about the margin of the mass, but the appearances in the field rather favor Lacroix's interpretation.

The next day the party, leaving Ax-les-thermes, drove to Foix, visiting on the way the gypsum quarries near Tarascon. The gypsum is of Triassic age and is seen to have resulted from the alteration of anhydrite. It contains intercalated marly beds holding dipyre, tourmaline and other minerals, which are believed to have been developed in them by an intrusion of ophite, which however is not exposed in the immediate vicinity.

On August 8th a visit was paid to a great mass of "Cipolin," intercalated in the gneiss near Arignac, which is locally rich in various minerals of the humite group and containing also spinel, plogopite, rutile, etc. The name "Cipolin" is given by the French geologists to any crystalline limestone intercalated in gneiss, even although it be free from the micaceous minerals which give to the typical "Cipollino" its distinctive character. This mass is from 200 to 300 meters wide and is identical in character with the limestone found in many parts of the Laurentian in North America. The enclosing gneiss is said by Lacroix to contain garnet, and also to differ somewhat in other respects from the granite of the vicinity of Ax-les-thermes. Its origin is unknown.

In the afternoon other large exposures of crystalline rocks near Cabre were visited. These consisted of epidosite, quarried for road metal, containing large lumps of malacolite in places and traversed by little graphite seams. This epidosite is believed to be an altered limestone, and is interstratified with bands of a peculiar dark fine-grained micaceous gneiss, exactly like that which is so uniformly associated with the limestones of the Laurentian in Canada and in the Adirondacks. The age of these crystalline rocks has not as yet been determined.

In the evening the party reached Vicdessos, some seventeen miles west of Ax-les-thermes, a most picturesquely situated little mountain village, from which excursions were made on the two following days. Our route on the first of these days led up to the quaint little village of Sem, where the renowned iron mines of Rancié were visited. The deposit here consists of a large body of limonite of irregular shape, enclosed in Silurian limestones and shales, and nearly coinciding with them in dip. It is worked by a series of levels the lowest of which is at Sem. This ore body which is very extensive has been mined for ages and formerly supplied ore to as many as fifty Catalan forges, which were in blast in the vicinity. The ore which is handled in a rather primitive manner is now sent to Tarascon, where it is smelted in the blast furnaces situated there. The limonite which makes up the mass of the deposit that has been worked up to the present time, is derived from the alteration of spathic iron ore into what the ore body changes in depth.

Taking a little path up the mountain beyond Sem, a summit marked by the Croix de Ste. Tanoque was reached, where an occurrence of lherzolite is well exposed. This is the original locality of the "Lherzoline" or "Lhercoulite" of Cordier, who mistook the somewhat altered and serpentenized rock for a distinct variety, to which he gave this name. The Jurassic limestones are here penetrated and altered by the intrusion, being bleached and crystallized, while the blocks of the light colored dipyre hornstones found near the contact are considered by Lacroix to be impure or marly bands which were interstratified with the limestones and which by virtue of their peculiar composition were able to fix the exhalations from the lherzolite, which the limestone was unable to do, and in this way to yield a rock rich in dipyre, microline, orthoclase and a variety of other silicates, the original differences in the composition of the beds becoming accentuated through the action of selective metamorphism.

Leaving Vicdessos the following morning, the party traversed the forest of Freychinède, climbing up great exposures of the Jurassic limestone, blue in color and often brecciated, the color being bleached out in spots and streaks precisely as in the Jurassic limestones of the Alps. In these limestones are several occurrences of lherzolite and ophite, which according to Lacroix have the form of laccolites, and which alter the limestones as described in the case of the occurrences near the Croix de Ste. Tanoque. Passing out of the forest and over the high pastures of the Col de Massat, where a number of shepherds and and cowherds in their picturesque dress were met, the party descended to the renowned L'Etang de Lherz, a beautiful little tarn, by the side of which the original lherzolite is seen. Here a great mass of this rock, dark brown on the weathered surface, penetrates the Jurassic strata, forming by far the most important occurrence of lherzolite in this portion of the Pyrenees. After lunch by the shore of the lake, the mist which had been gathering during the morning settled down as rain, and the party were obliged to hurry on to Massat, the "chef-lieu" of the canton, one of the most secluded little places in the Pyrenees, and one of the few places where the peculiar local costumes of the peasants of the Pyrenees still survive.

From Massat, early on the morning of August 11th, the party drove to Saint-Girons, stopping on the way to examine two or three ophite occurrences and at the Pont de Kerkabanac to see a contact of granite with schist. On the rocky bank of the little stream at this point the granite is seen breaking through the schist and including many little fragments of it. These are often angular, but in some cases appear to have been softened and somewhat drawn out. The "granitization" of these schists was said to be particularly pronounced. The appearance of the contact, however, was like that of any other ordinary granite contact, where the igneous rock has broken through a shattered mass of shale, caught up the fragments and baked them intensely.

At Saint-Girons the train was taken to Bagnères-de-Bigorre, another locality in the Pyrenees renowned for its thermal springs and hot baths, where during the afternoon the party visited the museum of Mr. Charles Frossard, rich in collections illustrating the natural history of the Pyrenees, after which they inspected the extensive marble cutting works and the baths.

About two miles from Bagnières-de-Bigorre is Pouzac, the well-known nepheline syenite locality. This rock, together with two masses of ophite, is exposed by the side of the railway line, cutting a series of limestones interstratified with marls, which is supposed to be of Triassic age. But little can be seen of the mutual relations of the several rocks or of their contacts. Lacroix states that the nepheline syenite and the ophite appear as little masses penetrating the Triassic limestones. He thinks the nepheline syenite is later in age than the ophite, which seems to surround it, but there appears to be no evidence from their field relations which makes it improbable that they are differentiation products of the same magma. The occurrence of the nepheline syenite, from which all the Pouzac material in collections the world over is derived, is barely sufficient in size to furnish a working face for a single small quarry. (See Fig. 3.) The rock is much decomposed, the sandy disintegration product being used for repairing the roads in the vicinity, but fresh material may be obtained from the numerous bowlders of decomposition. Small bostonite dikes occur in the limestone near the contact. The marly beds are filled with dipyre and the limestones contain little albite crystals, both minerals being attributed to the metamorphosing action of the ophite. The ophite itself is in many places filled with dipyre, which is, however, believed by Lacroix in this case to be the result of weathering.

On leaving Bagnières-de-Bigorre the party drove up the valley of Campan to Payole, a remote hamlet in the mountains, near which a quarry has been opened in a marble of Devonian or Carboniferous age, the stone being sent to Bigorre to be sawn and polished. The rock, which is known as Marbre de Campan, has a reddish or a grayish color and a linear brecciated structure, which produces a handsome effect on the polished surface, and which appears to be caused by certain laminæ in in the rock, rich in carbonate of lime, breaking apart under the pressure to which the rock has been subjected, while the intervening laminæ, rich in argillaceous matter and more plastic, have been forced in between the calcareous fragments and now cement these together.

One of the most interesting granite contacts seen on the excursion was reached from Payole, that, namely, of the Cirque d'Arbisson. Leaving Payole early in the morning on August 13th the party made their way through the Bois d'Arreiou-Tort and up over the moraines mantling the valley bottom and the lower slopes, and after several hours climbing reached the foot of the great Cirque. But little rock is exposed on the way up, but at the Cirque itself, whose walls tower up in the form of a great amphitheater of bare rocks skirted with talus piles, the exposures are magnificent. (See Fig. 5.)

The rocks composing the Cirque are Upper Devonian in age and consist of thinly banded strata, greatly contorted and twisted, and now converted into hornstones of several kinds, varying in character with the original composition of the rock. The unaltered rock was not seen, but it would seem to have been not unlike that worked in the quarries near Payole. The argillaceous bands, however, were probably more numerous and some of the bands were highly siliceous. The contortions and the breaking apart of the harder bands with flowing of the relatively softer layers, in this case the limestones, between the fragments is excellently seen. (See Fig. 6.) The original marly beds have been converted into epidote hornstones, while the more siliceous beds are converted into a flintlike material which is much darker in color. Some of the limestone bands, although greatly contorted, have retained their fine-grained texture and blue color, but owing to the shearing movements to which they have been subjected they have assumed, as is frequently the case in such occurrences, a sort of schistose structure. The limestone, however, is usually traversed by little streaks, coarser in grain and whiter in color, marking the first stage of a recrystallization and passage into marble. The limestones or calcareous bands in places contain large crystals of red garnet, resembling the well-known occurrences on the Stikine River, although the development of the crystals is not so perfect. Beautiful flat rosette-like groups of vesuvianite crystals also occur in places along the bedding planes, usually between the layers of epidote hornstone and the more siliceous bands. A few granite dikes and a mass of granite, apparently of comparatively small dimensions, occur on one side of the Cirque, while the other side is free from granitic intrusions. In these dikes, and also in the hornstone near the contact, axinite occurs in masses of considerable size. In the dikes this mineral occurs as rather coarsely crystalline streaks, in some cases on the walls and in others within the dike itself. In the hornstones it occurs as an impregnation, apparently partially replacing the other constituents of the rock. The petrographical character of the various rocks can be well seen in the immense talus piles at the foot of the cliffs, which also afford an excellent opportunity for collecting. From a petrographical standpoint this was one of the most interesting localities visited on the excursion.

The excursion, as originally planned, was to have terminated here, the party returning to Bagnières-de-Bigorre and then taking the train to Paris; but the majority of the party willingly accepted the proposal made by Professor Lacroix to extend the excursion by another day and visit Barèges. Accordingly, they left Payole on the morning of August 14th, and drove to Gripp, and thence walked to the Col du Tourmalet, over a great series of highly inclined and more or less altered clay slates, limestones, etc., of Upper Silurian and Devonian age. Magnificent views of the Pic du Midi, the highest point of the French Pyrenees, were obtained at a number of points along the route. The ascent was long, the day very hot, and shade by no means so abundant as could have been wished, but the Col du Tourmalet was at length reached, and the very abrupt descent made into the valley of the Bastan, over magnificent rock exposures. The granite appears near the head of this valley, and at its contact with the stratified series there appears a mass of rock consisting of a mixture of actinolite and axinite. The contact was not seen by the writer, but Professor Wolff, who saw it, states that the margin of the granite seemed to be well defined, although somewhat melted into the actinolite axinite rock above mentioned. As the evening was closing in, however, there was not sufficient time to make a study of the relations of the intrusion, the party being obliged to press on to Barèges.

The valley of the Bastan, in which Barèges is situated, is an excellent example of a valley half filled with morainic material, which is now deeply trenched and for the most part removed by the present stream. Patches of the moraine still remain adhering to the sides of the valley high above the present stream level. Great spaces swept bare by avalanches, here so destructive, can be seen at intervals, and high up on the steep slopes the terraces built by the French forestry department and by them planted with trees to prevent the snow from moving on certain of the more dangerous of the upper slopes, and in this way to avoid a repetition of the disastrous avalanches of former years.

At Barèges the excursion was brought to a close. The majority of those taking part in it, having on the following morning inspected the mineral springs for which the locality is renowned, left for Paris on the afternoon of August 15th, while a few members extended it by still another day and made a visit to the Cirque of Gavarnie, at the head of the Gave de Pau on the Spanish boundary, which is certainly one of the grandest spectacles in Europe, suggesting somewhat the great cliffs of the Yosemite valley (see Fig. 4).

The excursion was planned with the greatest care, and all the arrangements were personally supervised by Professor Lacroix, to whom the sincere thanks of the excursionists are due. Sleeping, as the party was obliged to do almost every night, in some remote mountain village, which was usually taxed to its utmost capacity to accommodate such an unusual influx of visitors, it was very difficult to make satisfactory arrangements in every case. Whatever comfort was to be had, however, the party enjoyed, and the excellent weather contributed greatly to the success of the excursion.

In entering upon a critical discussion of the phenomena observed, the writer feels that great care must be exercised in forming a judgment from what was of necessity a rapid and more or less incomplete study of the several occurrences. The members of the excursion were, moreover, at a serious disadvantage in not having any geological map of the districts visited. It was never possible to ascertain, except in a most general way, the areal distribution of any rock, the extent of any intrusion, or the distance to which any metamorphic changes could be traced. In preparing these notes, however, the information obtained in the field has been extended by a careful study of Professor Lacroix's published works, so far as they bear upon the localities in question, and a considerable number of thin sections of the rocks collected from the various occurrences, have also been examined.

In those cases where the granites of the Pyrenees were seen in contact with limestones, as, for instance, in the occurrences about Lac L'Estagnet, Pic du Camp Ras and Cirque d'Arbisson, the limestones near the contact were observed to contain various silicates which had crystallized out in them, as described above. Lacroix considers that in these cases, original differences in the composition of the beds influenced the nature of the minerals developed by metamorphism, but that the material for their growth was largely supplied by emanation from the intrusion. He believes that in the case of bands which were originally pure limestones, the minerals produced are garnet, epidote, zoisite, pyroxenes, amphiboles, quartz, feldspars and axinite. Where the original beds were impure, through the presence of siliceous or argillaceous materials, they are transformed into epidosites, garnet rocks, or feldspathic hornstones. Such limestones with silicates scattered through them, are not, of course, peculiar to the Pyrenees, they are seen in every Archean district in the world where limestones are found. The question always presents itself, as to how far these silicates represent original impurities in the limestone, and how far they are due to exhalations accompanying igneous intrusions. The limestones abutting directly against the igneous mass, even in the Pyrenees occurrences, are often free from these silicates In these contacts, however, the appearances go to show that the limestones during their recrystallization to marble have had added to them, in certain cases at least, as Lacroix holds, a certain amount of new material, probably from the waters and exhalations accompanying the intrusion; but this infusion of new material seems to be confined to a narrow zone about the contact, and is not by any means a regional phenomenon. In fact, in the occurrences at the Cirque d'Arbisson, some of the limestones of the Cirque itself, while greatly contorted, are practically unaltered in character, still retaining their original blue color and fine texture, and are free from all foreign minerals. The occurrence of axinite about the contacts does not seem to call for any especial notice, seeing that boron exhalations, giving rise to tourmaline, have been recognized as of frequent occurrence in contact zones by all authorities, having been found by Rosenbusch, even in the Barr-Andlau contact zone, which is always cited as affording evidence of the strongest kind, of the absence of metasomatic changes in the rocks about granite intrusions.

As mentioned above, in the district visited on the first two days of the excursion, that is, in the district about Lac l'Estagnet and the Cirque Camp Ras, there is between the altered limestone and the granite a zone, varying greatly in width but usually quite narrow, of what Lacroix terms "Roche Dioritique," and which is considered by him to have been formed by the solution of a portion of the limestone in the granite magma. This rock is said by Lacroix to occur only where the intrusion has limestone as a wall rock. It is a rock generally grayish in color and more basic in appearance than the granite, but of about the same size of grain, varying, however, considerably in grain and character from place to place. Lacroix states that a detailed study of it shows that it is not uniform in composition, but that it varies in minerological composition from a hornblende granite to a basic olivine norite, or even a peridotite. It completely surrounds detached masses of limestone, and has distinctly the appearance in the field of having been produced, as Lacroix believes, by a solution of the limestone along the margin of the granite. The conditions here are especially favorable for such a process of solution, as the limestone is broken up into a number of disconnected masses, thus exposing a large surface to the action of the granite.

No investigations into the chemical relations of the "Roche Dioritique" have been made, or at least none have been published; its exact chemical composition is unknown. This, however, is a subject on which information is especially required. It is most important to know in how far the composition of the "Roche Dioritique" approaches that of the normal granite of the district, with the addition of varying amounts of lime. It would seem that processes of differentiation must in any case have been at work in the mass after the solution had taken place, for it seems difficult to understand how any addition of lime to a granite magma can produce a peridotite. The only alternative, if this view of the origin of the mass is to be sustained, is to suppose that the exhalations given off by the magma first impregnated the invaded limestone in some places with minerals rich in iron, elsewhere with those rich in magnesia, and having thus produced out of the limestone a series of rocks of very diverse composition, the magma bodily dissolved them and thus obtained that irregularity in composition which caused it to crystallize out as rocks of such diverse composition as the mass cooled down.

The appearance in the field, however, in the opinion of the present writer, supports Lacroix's contention that this narrow band of "Roche Dioritique" was produced by the solution of the limestone in the granite magma about the contact. Detailed chemical studies and an accurate map of the area are, however, required before this contention can be proved, and it seems premature to say, as Lacroix does, "L'évidence de la transformation du granite par dissolution du calcaire est complète."[1] The development of this dioritic contact facies seems, even in the Pyrenees, to be unusual, and its volume as compared with that of the granite is insignificant, so that while, even if it be established that dioritic rocks may be produced by the solution of limestone in granite, it would scarcely indicate this as a probable origin for the great intrusions of these rocks met with in various other places.

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[1] Le granite des Pyrénées et ses Phénomènes de Contact. Bull des Services de la Carte Geol. de la France; No. 64, p. 60.

The other class of granite contacts to be considered are those in which the granite comes against slates, shales, and similar argillaceous strata. In the "Livret Guide" prepared for those taking part in the excursion, Lacroix states that there exist in the Pyrenees, notably in the Haute-Garonne and Hautes-Pyrénées, many granite contacts of the ordinary type, long since described, which present the regular and usual succession of spotted slates, spotted or nodular micaceous schists, and andalusite hornstones; but that the contact zones of the Haute-Ariège, visited on the excursion, were chosen because they present striking examples of a much more intense alteration, in character analogous to certain other French occurrences described by Michel-Lévy, which are characterized by a marked "feldspathisation" of the invaded rocks, indicating the "importance prépondérante" of deep-seated emanations in the case of igneous contacts, and affording evidence of a wholesale incorporation of the invaded rock.

"Au contact immédiat du granite, en effet, s'observe une zone constante dans laquelle les schistes et aussi les quartzites se chargent de feldspaths, soit par imbibition, ces minéraux jouant le même rôle que le quartz dans les schistes micacés, soit par injection en nature du granite lui-même. Il est possible de suivre, pas à pas, tous les stades de feldspathisation et les passages insensibles entre ces schistes feldspathisés (Leptynolites) et le granite lui-même." In certain cases, as in the valley of the Baxouillade (near the Cirque de Ras), he goes on to say, these two types of "feldspathisation" are superimposed in one and the same rock, giving the invaded rock a gneissic facies, which in certain cases is so pronounced that it resembles a veritable gneiss.

This process of "feldspathisation" may thus, according to Lacroix, take place in two ways, (1) by imbibition, and (2) by the injection of little veins of granite all through the invaded rock.

In the first case the shales next to the granite, in what is commonly called the hornstone zone, which contain, as in all contact zones, more or less biotite, have feldspar developed all through them by emanations accompanying the intrusion, being thus converted into micaceous feldspathic schists, called in France Leptynolites. The usual type of Leptynolite is stated to possess exactly the same structure as the non-feldspathic micaceous schists, but under the microscope it is seen to contain grains of feldspar (orthoclase or plagioclase), which, like the quartz grains in the rock, are allotriomorphic, their form being largely determined by the biotite. The proportion of the feldspar present is extremely variable; the mineral may be present merely as a few grains here and there in the rock, or the proportion may be greater —the feldspar in some cases being more abundant than the quartz—as in the case of some of the Leptynolite from near Baxouillade. When this is the case, and the rock becomes coarser in grain with an abundance of mica, it passes into a veritable gneiss.

In the second case the granite is injected at intervals in the form of little veins between the lamellæ of the schist, the veins when followed out to their feather edges fading away insensibly into the schist. This is known as "lit par lit" injection, and also gives rise to a gneiss.

The appearance of the contacts of this class visited on the excursion does not strike the observer as being at all unusual. The explanation which at once suggests itself is that the acid granitic magma which has, by virtue of its acidity, apparently eaten into and dissolved the limestone in certain places and to a limited extent, has not been able to produce any marked effect on the shale. It has forced its way into the shattered strata along the contact, in the usual manner, sending a swarm of little dykes or veins into it in places, and everywhere baking it into a more or less micaceous hornstone-like mass. Fragments of the altered shale, abundant near the contact, less so at some distance, lie scattered about in the granite. These often retain their angular character, but at other times are seen to have been somewhat softened and pulled out into more or less elongated forms, appearing as dark streaks in the granite. The shale has been recrystallized, as in the case of every hornstone, the phenomenon being, of course, more pronounced in the separated fragments which are completely enveloped in the granite magma. The "lit-par-lit" injection is a not unusual phenomenon of contact in all igneous intrusions, and merely produces a mechanical admixture of granite with shale along the immediate contact of the intrusion without in any way necessarily altering the composition of either rock, or producing anything which is not manifestly a mixture of two distinct rocks. The appearance of feldspar in the altered shale — its "feldspathisation par imbibition" — does not necessarily indicate any addition of material. If there were not alkalies in the shale, the appearance of feldspar in the altered rock would be an evidence of the addition of these elements. But, as the analysis of shales from all parts of the world show, alkalies are almost invariably present, amounting on an average to about 4.75 per cent. This would, in the case of a thoroughly recrystallized rock, afford the material for as much as 25 or 30 per cent. of feldspar, and it would seem that there is seldom more, or in fact as much as this, present in the Leptynolite.

Gneissic rocks of a peculiar type found continually associated with the Laurentian limestones of Canada, and which have precisely the character of the more altered forms of these Leptynolites, when analyzed have been found, in many cases, notwithstanding their content in feldspar, to have a chemical composition identical with that of ordinary roofing slate, being in fact nothing more than shales which are completely recrystallized. On the other hand, thin sections of the most altered leptynolite from Pont de Kerkabanac contain more feldspar than would be expected in an altered shale.

While, then, it is impossible to assert that there has been no addition of material to the altered shale, no evidence seems to have been brought forward that there has been such addition, or that these occurrences differ from the ordinary type of contact

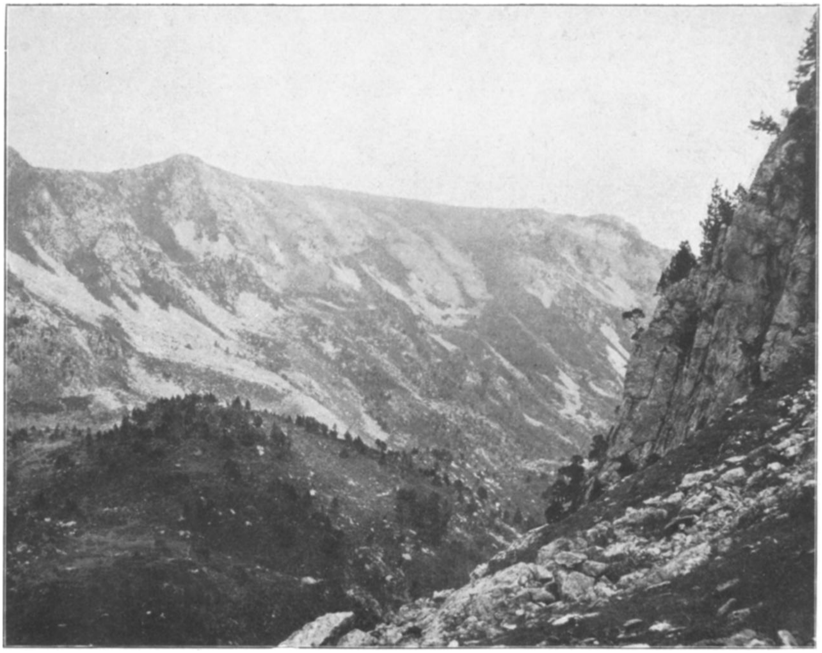

Fig. 1.

Near L'Etang de l'Estagnet.

Ridge of granite in distance. On right, cliff of thinly banded limestone, much altered and filled with garnets.

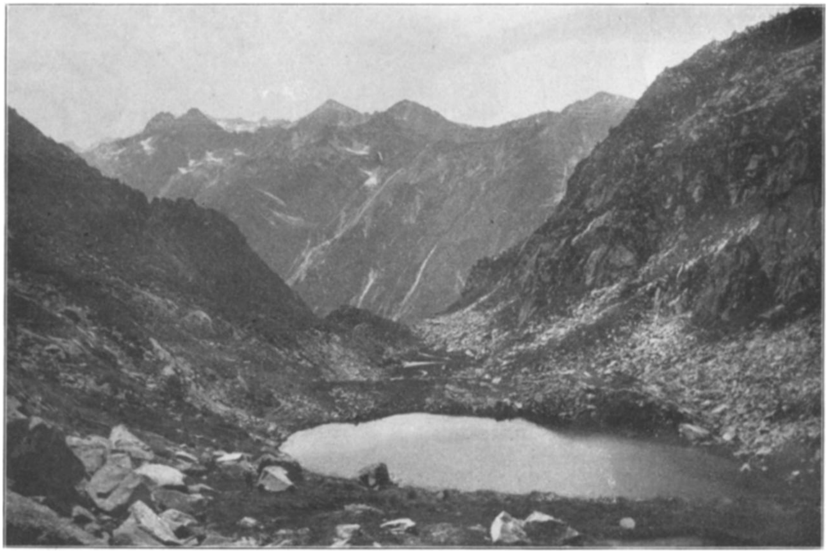

Fig. 2.

L'Etang de Baxouillade.

In foreground, granite with inclusions of schist and "Roche Dioritique." The mountains in the distance are composed of granite with pre-Cambrian limestone and "Roche Dioritique." The depression in the center of the range is formed by a Permo-Carboniferous limestone, which is altered by the granite.

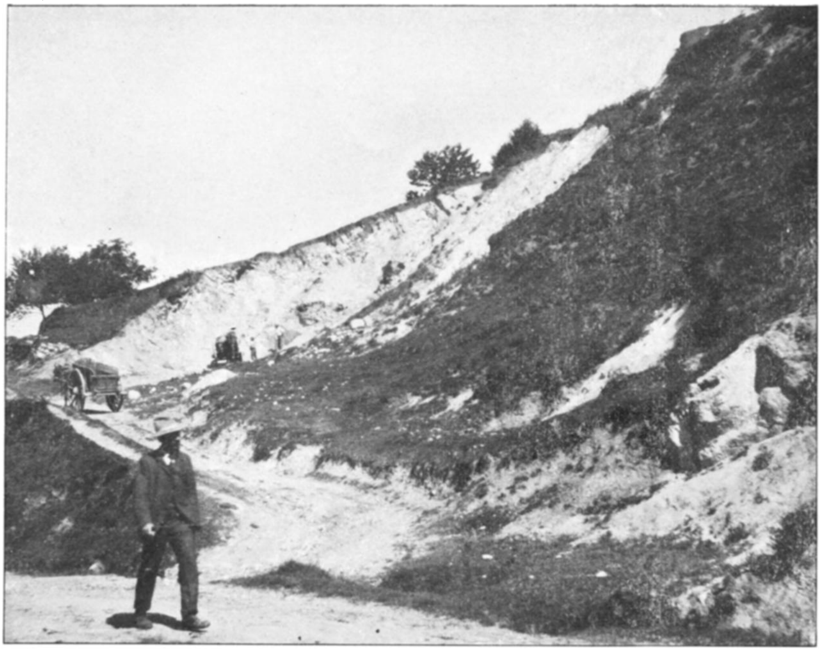

FIG. 3.
Quarry in Nepheline Syenite—Poussac.

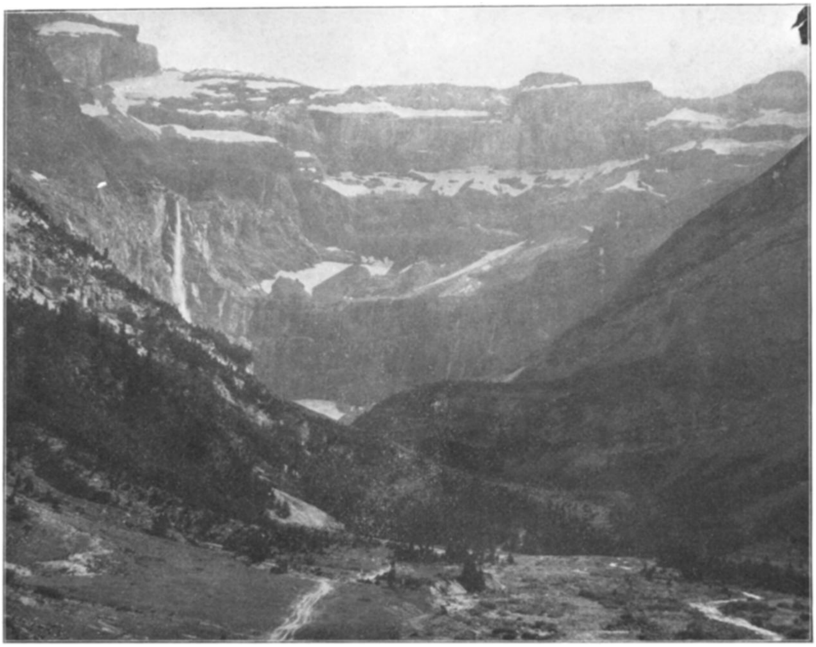

FIG. 4.
Cirque de Gavarnie.

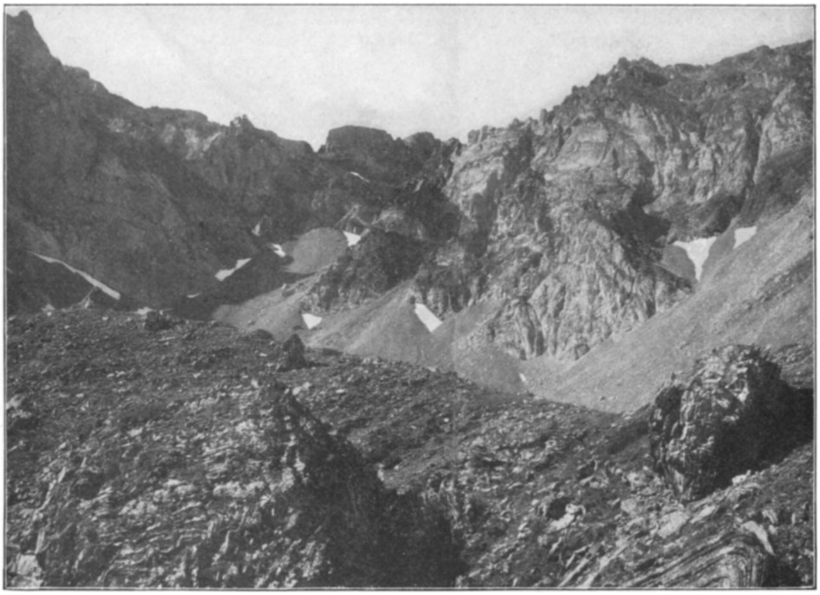

Fig. 5.
Cirque d'Arbisson.

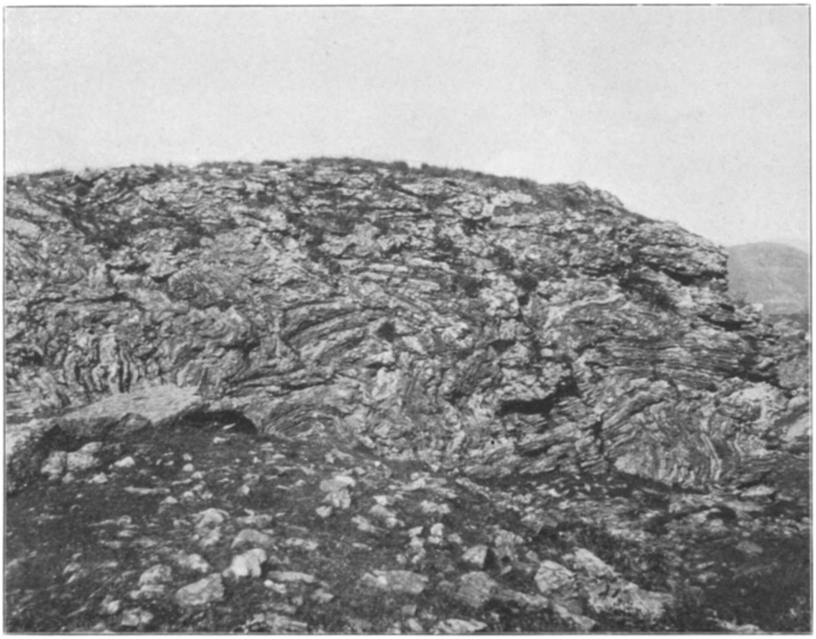

Fig. 6.
Contorted Strata at the Cirque d'Arbisson.

zones. What is required to establish this, is an exhaustive series of chemical analyses of carefully selected material, showing the composition of certain definite beds in their original and altered forms. Such an investigation would be of the greatest interest and highest importance to geological science at the present time.

Although, therefore, it is possible that some of the Archean gneisses which now have no longer the composition of any ordinary sediment, may represent shales which have been transfused with new material by emanations accompanying granitic intrusions, the studies hitherto made of these Pyreneean contacts do not, in the opinion of the writer, afford any conclusive evidence that such emanations have this transforming power. Still further are they from establishing the contention that granitic intrusions are merely great areas of shale or other sedimentary rocks changed in situ into granite, which is the view of their origin held by Michel-Lévy and Lacroix. "Je considère donc toutes ces couches métamorphiques isolées aujourd'hui au millieu du granite comme le résidue non digéré des assises sédimentaires dont le granite á pris la place."[1] "La mise en place du granite s'est effectuée par dissolution graduelle des roches sédimentaires dont il occupe la place."[2] This conclusion would, of course, if established, be of the greatest interest, but the evidence hitherto put forward seems quite insufficient for that purpose.

The metamorphism of the sedimentary strata in the vicinity of the intrusions of the basic rocks (ophite and lherzolite) is also attributed by Lacroix largely to the action of emanations from deep-seated sources. "L'impuissance de la lherzolite à opérer des transformations métamorphiques par l'action de sa propre substance est démontrée par l'absence de zones de passage entre elle et les sédiments métamorphiques et par la nature des minéraux produits à son contact. . . . . La roche modifiée a fourni une partie des éléments nécessaires à la formation des mineraux néogènes, mais beaucoup de ces éléments ont été nécessairement apportés des profondeurs, sous forme d'émanations, ayant une composition chimique différent de celle qu'à priori on pouvait supposer, étant connue la composition de la lherzolite."[1] There is, however, here again the same absence of the chemical evidence which would serve to definitely establish this conclusion.

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[1] LACROIX: Livret, Guide, p. 15.

[2] LACROIX, Le granit des Pyrenées, etc., p. 3.

It is also to be noted that in the Pyrenees, dynamic action has followed the development of the contact zones above described. Lacroix observes that the minerals produced by the contact metamorphism are often much deformed by subsequent movements, but adds: "J'ai pu constater avec précision que les phénomènes de contact jouent un rôle prépondérant dans la production des nombreuses roches métamorphiques que l'on rencontre dans toute l'étendue de la chaîne."[2] As, however, it is a matter of extreme difficulty, if not an impossibility, in all cases to determine to which class of metamorphic agencies certain rocks are due, the question as to how far dynamic action may have at least contributed to some of the changes attributed to contact action is one which cannot be considered as entirely settled.

To sum up therefore it may be said, that while the transfusion of a certain amount of material into the limestones along the immediate contact of the intrusions and also a solution of the limestone to a limited extent in certain cases seems highly probable; the wholesale transformation of limestone into diorite, or of shale into gneiss and granite, which has been described in the case of these contact zones of the Pyrenees, is as yet very far, indeed, from being proved.

FRANK DAWSON ADAMS.

GEOLOGICAL DEPARTMENT
McGILL UNIVERSITY.

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[1] LIVRET, Guide, p. 5.

[2] Les Phénomènes de contact de la Lherzolite et de quelques Ophites des Pyrénées. Bull. des Sciences de la Carte Géol. de la France, No. 42, p. 133.